622415

2 SHEETS
SHEET 2

Fig. 2

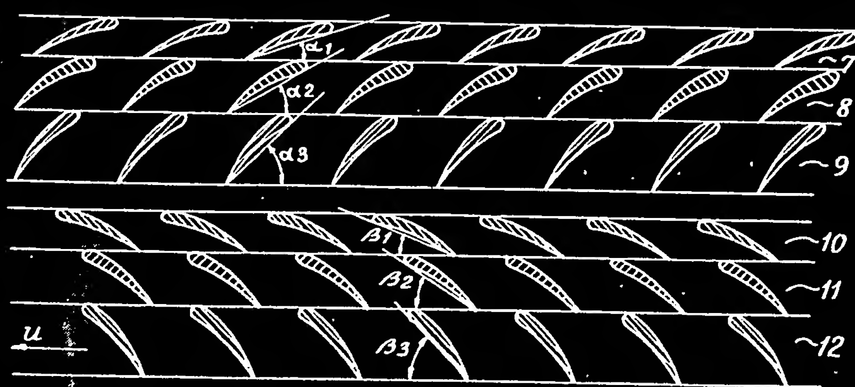
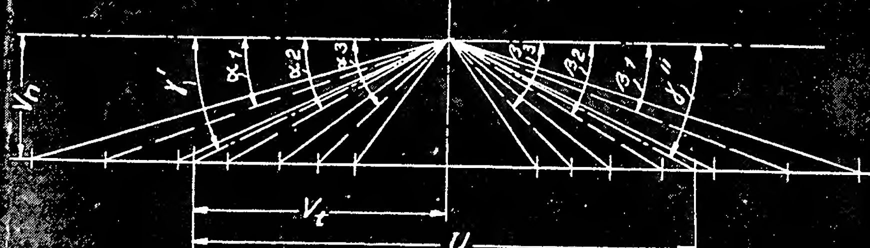


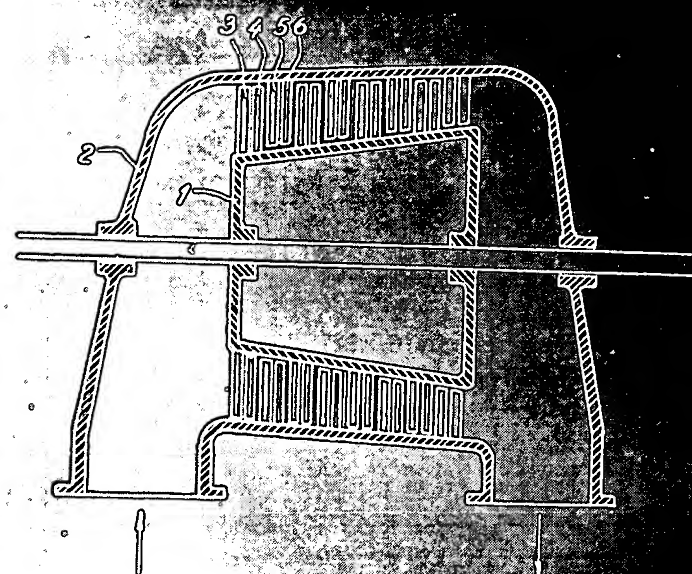
Fig. 3



H.M.S.O. (Ty. P.)

[This Drawing is a reproduction of the Original on a reduced scale]

Fig. 1



PATENT SPECIFICATION

622,415

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Complete Specification Accepted: May 2, 1949.

Index at acceptance:—Classes 110(i), D1c; and 110(iii), B2b2.

COMPLETE SPECIFICATION

Improvements in and relating to Multi-Stage Compressors, Pumps, Turbines, or similar Rotary Machines or Engines

I, JAKOB KNUDSEN JAKOBSEN, a subject of the King of Denmark, of Nr 32, Frimestervej, Copenhagen, Denmark, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to a multi-stage compressor, pump, turbine, or similar machine or engine consisting of two oppositely rotating rotors or, alternatively of a rotor and a stator, whereby the meridian section in the mean flow path may be rectilinear or curved. In the case of a curved shape the invention preferably refers to machines or engines in which the meridian section runs along a curved line the subtangent of which has constantly the same sign or in a particular case may be zero. The term "subtangent" of a point of a curve is defined as that part of the axis of abscissae which lies between the section point of the tangent to the curve at that point with the axis of abscissae and the projection of the said point of contact on the said axis.

The purpose of the invention is a certain arrangement of the rotor blades or the rotor- and guide blades in such compressors, liquid pumps, etc.

In the machines or engines of the said type generally used the energy conversion takes place in successive, oppositely rotating single rings of blades or in successive, rotating and stationary, single rings of moving blades and guide blades respectively. Two such rings of blades following one upon the other form a stage in the machine or engine (compressor stage, pump stage, etc.).

It has been proposed to mount two or more rings of blades in series within one or more stages or stage parts, and the present invention consists in a special construction of such a machine or engine where in some of or in all the stages or stage parts the blading is formed by two or more series-mounted rings of blades, so-called grid series, which term refers to the fact that a single ring of blades forms a grid of blades, so that several rings of blades mounted in series form a grid series. If both parts of a stage in the engine comprise two or more rings of blades, the stage will thus consist of two successive grid series moved in relation to each other.

The losses in a blading in accordance with the formerly proposed arrangement will normally be smaller than in the case of the same deflection in a single ring of blades, a single grid, but they will be of the same order as the losses occurring at the alternate mounting of single guide blade grids and single rotor blade grids with an energy conversion as mentioned above. In accordance with the present invention it is, however, possible to attain a rather substantial reduction in the losses by a suitable mounting of the grids in relation to each other, viz., in such a manner that the so-called tired boundary layer departing from a grid does not impinge on the blades in the following grid in the same series but passes between them without touching them.

In accordance with the invention the grid series are built up in such a way that the blades in two successive rings of blades or grids in a series are displaced relative to each other, said two successive rings of blades in a series having an equal number of blades, and that in the downstream ring the blades have their leading edges in line with or in the vicinity of the centre of the space or clearance between the trailing edges for the blades in the preceding ring, e.g., within a distance of one fourth of the width of the space to one side or the other of the said centre, the rings of blades within a series following immediately upon each other with no or only a slight clearance.

Part of the above-mentioned losses in an ordinary blade grid derive from the

[Price 2/-]

fact that the boundary layer departing from the blade profiles flows off at a lower velocity than the so-called sound flow. The differences in velocity that are thus present in the medium flowing off from the grid will cause frictional forces in the medium whereby the differences in velocity will gradually be eliminated, but as this elimination is effected by means of frictional forces, it is accompanied with losses. By two or more rings of blades or grids being mounted successively in series in accordance with the present invention is attained that the kinetic energy in the sound flow is utilised directly whereby a great part of the losses deriving from the elimination of the differences in velocity are avoided. The arrangement according to the invention is of great importance with regard to the good conditions obtained for the passing of the flow from one stage to a following. It is a fact that the very presence of the blades involves certain local reductions of the flow velocity, viz., due to the so-called wake-effect in the flow at those places which lie in continuation of the blades. The irregularities in the flow occurring thereby are detrimental to the inflow of the medium into a stage from a preceding stage but said irregularities are considerably diminished by the dividing up of the single stages and the arrangement of the blades therein in accordance with the invention as the wake-effect thereby to an essential degree is evened out whereby a considerable improvement of the efficiency is obtained.

It is also an essential advantage of the invention that the individual grids in the grid series are placed immediately upon each other with no or only a slight clearance, which is possible owing to the fact that the individual grids in a grid series do not move in relation to each other. Said feature involves the essential advantage that the building length of the machine or engine may be considerably reduced which especially is of importance in an engine having many stages.

The securing of the blades may be effected in some known way either in longitudinal or in circumferential grooves, possibly with two or more rings of blades in the same groove.

Further embodiments of the invention will appear from the following specification and from the patent claims.

On the accompanying drawing the invention is illustrated by an embodiment example.

Fig. 1 showing diagrammatically an axial section through a compressor in accordance with an embodiment of the invention;

Fig. 2 on a larger scale a section through the blading in a machine or engine with three grids in series in each part of a stage, which section is made on a cylindrical surface and next developed, and

Fig. 3 the velocity triangles for the blades corresponding to Fig. 2.

In Fig. 1, 1 designates a rotor carrying a number of rings of rotor blades mounted two by two in series as indicated by 3 and 4, while 2 designates the stator or the case carrying the rings of guide blades 5 and 6 which are likewise mounted two by two in series. The arrows below in Fig. 1 indicate the direction of motion of the medium through the compressor.

In accordance with Fig. 2 it is presupposed that there are three grids in series in both of the two parts which together form a stage in the machine or engine. 7, 8 and 9 designate the grids in a grid series which must be imagined stationary, while 10, 11 and 12 are grids in a series moving at the velocity of rotation u. The designations α_1, α_2 and α_3 and β_1, β_2, and β_3 designate the blade angles for the blades in the individual grids 7—12, a blade angle being defined as the angle between the velocity of rotation u and the chord of the blade profile.

As appears from Fig. 2 the individual grids in each series follow immediately upon each other, and the leading edges for the blades in the second and third grids in each series are in line with the centre of the space between the trailing edges for the blades of the preceding grid.

The angles used in Fig. 3 correspond to the angles mentioned above in Fig. 2, the direction of the mean velocity through a grid in practice coinciding with or approximately coinciding with the direction of the chord of the blade profile.

It is of great importance for attaining a good efficiency that in each grid series there occurs a suitable conversion between velocity and pressure. In accordance with the invention the best conditions are attained when—preferably at all points of the blade length—the blade angles fulfil the condition:—

$$0 < \frac{\sin \delta^{I}}{\sin \delta^{II}} < \frac{1}{3}$$

where δ^{I} is equal to half the difference and δ^{II} equal to half the sum of two successive blade angles in one and the same grid series, viz., $\delta^{I} = \frac{\alpha_2 - \alpha_1}{2}$, $\delta^{II} = \frac{\alpha_2 + \alpha_3}{2}$, etc.

The condition stated should preferably be fulfilled with regard to both grid series.

Moreover the blade angles for the blades in successive grids in a series in accordance with the invention should fulfil the following condition, in at least one point of the blade length:—

$$\frac{1}{3}<\frac{\tan\gamma^{1}}{\tan\gamma^{11}}<3,$$

where γ^1 designates the angle between the so-called mean relative velocity in a grid series and the peripheral velocity u, while γ^{11} is the angle between the mean velocity in the adjacent grid series and the peripheral velocity u, see Fig. 3 which angles are determined by the blade angles, it being possible in the case of a stage consisting of two grid series, each of which comprises two rings of blades or grids, to use the following approximate expression:—

$$\tan\gamma^{1}=\frac{\sin\alpha_1+\sin\alpha_2}{\cot\alpha_1\times\sin\alpha_2+\sin\alpha_1\times\cot\alpha_2}\quad\text{and}\quad\tan\gamma^{11}=\frac{\sin\beta_1+\sin\beta_2}{\cot\beta_1\times\sin\beta_2+\sin\beta_1\times\cot\beta_2}$$

in which expression the said angles has the meaning shown in Fig. 2.

For the attainment of a good efficiency it is furthermore of importance that the so-called secondary flows, i.e., flows in the longitudinal direction of the blades, are kept as small as possible. This is best attained by letting the velocity disposition in the engine correspond as far as possible to the so-called potential eddy, or free vortex, whereby the tangential velocity of the working medium is inversely proportional to the distance from the axis of rotation while its axial velocity becomes constant at all points. For the fulfilment of this condition it must be required that, approximately at any rate, the blade angles fulfil the condition:—

$$\frac{\tan\gamma^{1}+\tan\gamma^{11}}{\tan\gamma^{11}}=k\times r^{2},$$

where k is a constant dependent on the number of revolutions to which the engine is built, while r is the distance from the axis of rotation.

Finally it is of importance for the attainment of a good efficiency that the ratio of the component v_n (see Fig. 3) of the mean velocity at right angles to the grid to the component v_t parallel to the grid is lying within certain limits, viz.,

$$\frac{1}{3}<\frac{v_n}{v_t}<3$$

which condition leads to

$$\frac{1}{3}<\tan\gamma^{1}<3\quad\text{and}\quad\frac{1}{3}<\tan\gamma^{11}<3.$$

In an engine with two grids in each series it may be expedient that the two blade angles corresponding to each other in the two parts of a stage are completely or approximately equal (i.e., that $\alpha_1=\beta_1$ and $\alpha_2=\beta_2$) at least at one point of the blade length.

In embodiments with three or more grids in a series it may correspondingly be advantageous that the condition $\alpha_1=\beta_1$, $\alpha_2=\beta_2$, $\alpha_3=\beta_3$, etc. be fulfilled at any rate approximately in at least one point of the blade length. This is the case in the embodiment shown in Figs. 2 and 3, whereby also γ^1 gets equal to γ^{11}, i.e. that the reaction ratio is 50 per cent.

Finally it has proved advantageous that in embodiments with two or more grids in series the blade angles fulfil the following condition in at least one point of the blade length:

$$\frac{1}{3}<\tan\frac{\Sigma}{n}<3$$

where n is the number of grids in the series, while means the sum of the blade angles, viz.

$$\Sigma=\alpha_1+\alpha_2+\alpha_3+\ldots\ldots\alpha_n\ \text{or}\ \Sigma=\beta_1+\beta_2+\ldots\ldots\beta_n$$

It must be pointed out that even if in Fig. 1a machine is shown which might appropriately be termed an axial flow machine, the inventioon may also be applied in the case of radial flow machines or engines and in machines or engines where the flow occurs along a cone surface, or in other intermediate forms

between axial flow and radial flow machines or engines.

On account of the good efficiency which may be attained in a compressor constructed in accordance with the invention, such a compressor will be well suited for application in connection with a gas turbine.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. Multi-stage compressor, pump, turbine, or similar machine or engine consisting of two oppositely rotating rotors or alternatively of a rotor and a stator, in which the meridian section in the mean flow surface is rectilinear or curved, and for which in some or in all of the stages or stage parts the blading is formed by two or more series-mounted rings of blades, so-called grid series, characterised in that these grid series are built up in such a manner that the blades in two successive rings of blades or grids in a series are displaced in relation to each other, said two successive rings of blades in a series having an equal number of blades, and that in the downstream ring the blades have their leading edges in line with or in the vicinity of the centre of the space or clearance between the trailing edges for the blades in the preceding ring, e.g. within a distance of one fourth of the width of the space to one side or the other of the said centre, the rings of blades within a series following immediately upon each other with no or only a slight clearance.

2. Machine or engine as claimed in claim 1 characterised in that, preferably at all points of the blade length, the blade angles fulfil the condition:

$$0<\frac{\sin \delta^{1}}{\sin \delta^{11}}-\frac{1}{3},$$

where δ^1 is equal to half the difference and δ^{11} equal to half the sum of two successive blade angles in a grid series.

3. Machine or engine as claimed in claim 1 or 2, characterised in that the blade angles for the blades in successive grids in a series at one point at least of the blade length fulfil the following condition:

$$\frac{1}{3}<\frac{\tan \gamma^{1}}{\tan \gamma^{11}}<3,$$

where γ^1 designates the angle between the mean velocity in a grid series and the peripheral velocity, while γ^{11} is the angle between the mean velocity in the adjacent grid series and the peripheral velocity, which angles are determined by the blade angles, it being e.g. in a stage consisting of two grid series, each of which comprises two rings of blades or grids, possible to use the following approximate expression:

$$\tan \gamma^{1}=\frac{\sin \alpha_1+\sin \alpha_2}{\cot \alpha_1 \times \sin \alpha_2+\sin \alpha_1 \times \cot \alpha_2} \text{ and } \tan \gamma^{11}=\frac{\sin \beta_1+\sin \beta_2}{\cot \beta_1 \times \sin \beta_2+\sin \beta_1 \times \cot \beta_2}$$

where α_1, α_2 and β_1, β_2 are the blade angles in each other of the two series of the stage.

4. Machine or engine as claimed in one or more of the preceding claims, characterized in that the blade angles at least approximately fulfill the condition:

$$\frac{\tan \gamma^{1}+\tan \gamma^{11}}{\tan \gamma^{11}}=k \times r^{2},$$

where k is a constant dependent on the number of revolutions for which the engine is built, while r is the distance from the axis of rotation.

5. Machine or engine as claimed in one or more of the preceding claims, characterized in that at least at one point of the blade length the blade angles fulfil the condition:

$$\frac{1}{3}<\tan \gamma^{1}<3 \text{ or } \frac{1}{3}<\tan \gamma^{11}<3,$$

or both, where γ^1 and γ^{11} have the meaning stated in claim 3.

6. Machine or engine as claimed in one or more of the preceding claims and with two grids in each series, characterized in that the mutually corresponding blade angles α_1 and β_1, and α_2 and β_2 respectively, in the two parts of a stage are equal at one point at least of the blade length.

7. Machine or engine as claimed in one or more of the preceding claims and with three or more grids in a series, characterized in that the mutually corresponding

blade angles α_1 and β_1, α_2 and β_2, α_3 and β_3 etc. are completely or approximately equal at one point at least of the blade length.

8. Machine or engine as claimed in one or more of the preceding claims and with two or more grids in a series, characterized in that at one point at least of the blade length the blade angles fulfil the condition:

$$\frac{1}{3} < \tan\frac{\Sigma}{n} < 3$$

where n is the number of grids in the series, while Σ means the sum of the blade angles, viz.

$$\Sigma = \alpha_1 + \alpha_2 + \ldots\ldots \alpha_n \text{ or } \Sigma = \beta_1 + \beta_2 + \ldots\ldots \beta_n$$

9. Machine or engine substantially as described with reference to the accompanying drawing.

Dated this 20th day of March, 1947.

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